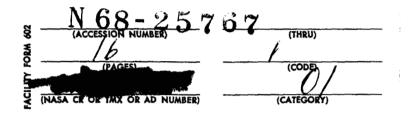


FLOW STRUCTURE BEYOND A POORLY STREAMLINED BODY

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### FLOW STRUCTURE BEYOND A POORLY STREAMLINED BODY

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ABSTRACT. The results are discussed from an experimental investigation of the characteristics of average velocities and pressures, as well as the pulsation pressure in the wake beyond a cone and a step in a channel with two diameters. In particular, a detailed analysis is made of the zone of circulation flow immediately beyond the flat bottom of the cone. The averaged bottom pressure and its pulsations were measured, as well as the velocity profiles and pressure in the wake; the boundaries of the zone of circulation flow and zone of return flow were determined.

In recent years, the attention of researchers has been attracted by the study of the characteristics of the discontinuous flow in the wake beyond a poorly streamlined body placed in an unlimited flow or in a channel [1-7]. This problem is of interest both in principle and directly for practice, since the area of return flow has an essential influence on the effectiveness of various technical devices. Most of the works just cited are dedicated to a study of the characteristics of the averaged flow, while the last two works ([6-7]) analyze the nature of the turbulence in a flow beyond a step in a flat channel.

In the present work, we set ourselves the task of accumulating experimental data on the characteristics of the averaged and pulsation flow in the wake beyond a cone, as well as beyond a step in a flat channel with various degrees of blocking. The flow characteristics in the wake beyond the cone are compared to the corresponding characteristics of a streamlined rotation body [8].

# 1. Object of Investigation, Experimental Equipment

The axisymmetrical wake beyond a poorly streamlined body was produced by blowing a stream past a cone in closed type wind tunnels with an open test section with nozzle diameters of D = 440 and 2200 mm. The diameter of the bottom section of the cone d = 100 mm, its height is 120 mm and the peak angle is 45°. The measurement of the mean velocities and pressures, as well as the pulsation pressure on the bottom cross section were performed in the small wind tunnel. The cone was fastened in place by a horizontal holder. Investigation of the velocity pulsations in various cross sections of the wake beyond the cone were performed in the large diameter tunnel. In this case, the cone was supported on eight tension lines, and the plane of measurements contained no lines.

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<sup>1</sup> Numbers in the margin indicate pagination in the foreign text.

In order to measure the average and pulsation pressure at the bottom cross section of the cone, two removable covers were used. The first cover contained 19 drainage apertures, one each 5 mm, connected through the support by vinyl chloride tubes to a multiple manometer. The second cover contained three induction pressure transducers, one located in the center and the other two along the vertical diameter at distances of 0.7 times the radius of the bottom cross section, symmetrically relative to the center. Each transducer body was 10 mm in diameter, and the diameter of the receiver aperture was 0.5 mm. The signal from each transducer was fed to an amplifier and subsequently to the loops of an oscillograph.

The averaged velocities and pressures in the wake were measured through the vertical cross section using a three-tube fitting. In [9], it is stated that measurements of the flow by the zero and absolute methods give identical results. In this work, we use the absolute method of measurement. Using the measured pressure drops in the outer tubes and the central tube of the three-tube fitting, we calculated the magnitudes and directions of velocities at each point, the total and also the static pressure, equal to the difference between the total pressure and the dynamic pressure.

In order to measure the intensity of the turbulence, as well as the average velocities, we used a disa elektronik thermoanemometer, the single thread transducer of which had a diameter of 10  $\mu$  and a length of 1.4 mm. Measurement of the velocity pulsations in the wake beyond the streamlined body, which had a middle cross sectional diameter of 60 mm and a length of about 400 mm, were performed in the small tube with the model supported by six tension members.

Investigation of the discontinuous flow resulting from the sudden expansion beyond the step in a closed channel was performed using a special installation, consisting of a settling chamber to which a wooden, closed valve was connected. The diagram of the channels is presented below on Figure 13, their geometrical parameters in Table 1. A tube 100 mm long connected the channel to the input collector. The device operated in the indraught mode.

TABLE 1

Model No.	Н	h MM	L MM	$\overline{H}=H/h$
1	80	100	860	0,8
2	80	200	1700	0,4
3	62	100	1000	0,62
3	162	100	1000	1,62
3	280	100	1000	2,80

Two models had constant height H of narrow intake section (tube), but different step heights h. The other three models had constant step height and variable height of intake section, which was achieved by moving the wall opposite to the wall with the step. The models were made rather long so that the reverse flow zone would in all cases be contained in the channel. The width of the channels was 800 mm. Measurements were performed in the plane of symmetry of the channel 400 mm from the side walls. The averaged velocities were measured using the three-tube fitting, Pitot--Prandtl tubes, as well as the thermoanemometer, for which sealed slits were made in the channel walls. Drainage apertures and nipples were provided in the walls and on the step for the measurement of static pressure. The pressure drops were measured using a multiple naometer.

To allow visual investigation of the flow picture, the side wall was made of plexiglass in two of the models. Visualization was achieved using small bundles of white silk threads suspended on thin wires across the channel, as well as by coloring the internal surface of the model black. The silk threads were photographed through the transparent wall of the model.

# 2. Experimental Results

Figure 1 shows the profiles of averaged velocity u(r) and excess total pressure  $\Delta P_0 = p_0 - p_\infty$ , produced using the three-tube fitting with measurements beyond the cone. The flow velocity was  $u_\infty = 28.8$  m/sec. Curve 1 corresponds to the surface of zero longitudinal velocity; curve 2 shows the surface delineating the closed circulation zone. Its ordinates  $r_2$  were calculated on the basis of

the condition  $\int_{0}^{r_2} urdr = 0$  using the measured profiles of the longitudinal

component of averaged velocity. Analysis of Figure 1 shows that an increase in the flow velocity occurs near surface 2. This deformation of the velocity field was also noted during flow around a poorly streamlined body in a closed channel [3]. The deformation of the velocity field ends at a distance equal to approximately two ordinates of surface 2.

Figure 2 shows the distribution of the pressure coefficient  $\overline{p}$  =  $(p - p_{\infty})/\frac{1}{2} \rho u_{\infty}^2$  in the same cross sections of the wake. As we can see from these data,  $\overline{p}$  reaches values of 0.55-0.60 on the axis of the wake and in the area of zero longitudinal velocity. The pressure profile also has the same approximate configuration in the case of reverse fluid flows when a stream propagates into an oncoming flow [4].

The results of measurement with the three-tube fitting in the area of low values of  $\overline{p}$  are less precise, since here the static pressure is determined as the small difference of two large quantities. We can note, however, that in the area of the end of the vortex zone, the rarefaction is decreased and becomes more even across the cross section. It is shown in [8] that in the wake beyond

a rotation body of streamlined form, there is no rarefaction on the axis of symmetry. Immediately beyond the rotation body, a slight pressure gradient occurs, the maximum value of  $\overline{p}$  on the axis being +0.01.

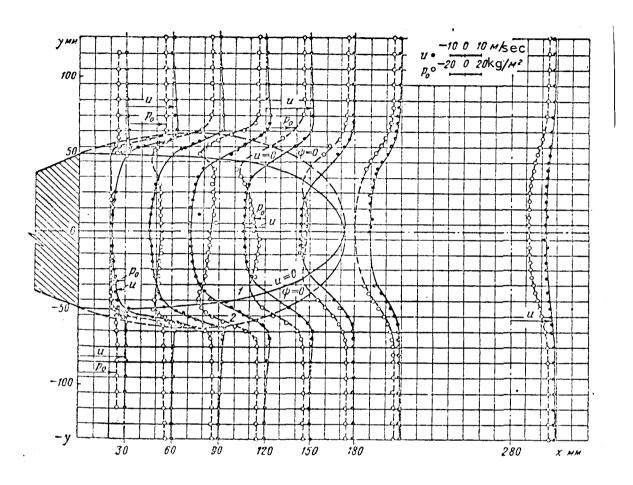


Figure 1

Measurement of the static pressure at the bottom cross section of the cone showed that at oncoming flow velocities  $u_{\infty}$  = 16.4-48.8 m/sec, the pressure coefficient is practically constant along the radius, equal to 0.30. Measurements of the pulsation pressure on the bottom cross section of the cone showed that the amplitude of the pressure pulsations at the center is only one half the amplitude near the edge of the bottom cross section, amounting to  $p'/(\rho/2)u_{\infty}^2$  = 0.04 at  $u_{\infty}$  = 28.8 m/sec.

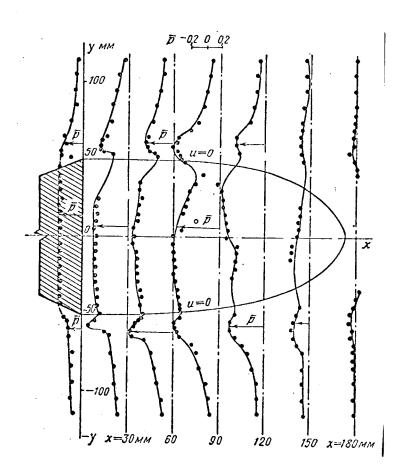
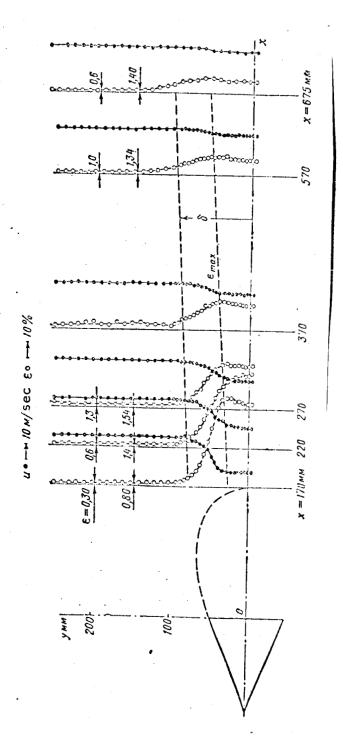


Figure 2

Figure 3 shows the profiles of averaged velocities (black points) and intensities of turbulence  $\varepsilon = \sqrt[V]{\overline{u'^2}}/u$  (white points) in the wake beoynd the cone at  $u_\infty = 28.8$  m/sec. The averaged velocities here were also measured using the thermoanemometer. The measurements were limited to the area of the wake within which the fluid in the wake moves only in the primary direction.

The results of the experiment allowed us to determine the length of the area of reverse flow in the wake beyond the cone:  $l \approx 170$  mm or  $l \approx 3.4$  r<sub>0</sub>, where r<sub>0</sub> is the radius of the bottom cross section of the cone. Precise determination of the length of the area of reverse flow is rather difficult. The intensity of the turbulence in the area of the wake adjacent to the sector of closed circulation flow is quite great (Figures 3 and 4) and its attenuation in the transverse direction occurs at a distance exceeding the thickness of the wake as determined from the averaged velocities by a factor of more than 2. Figure 4 shows for comparison the profiles of turbulence intensities in the wake beyond a body of rotation.



Igure 3

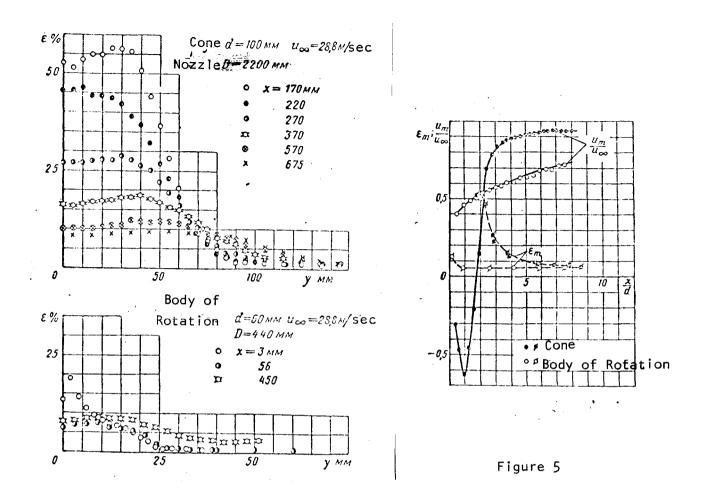


Figure 4

Figure 5 shows the distribution of velocities and turbulence intensities on the axis of the wake beyond the cone and beyond the body of rotation. It becomes obvious that in the wake beyond the cone, the increase in mean velocity on the flow axis occurs more rapidly than in the wake beyond the body of rotation, which is a result of the higher level of turbulence in the former case.

Figures 6-8 and 9-11 show the measured intensities of pulsations in the longitudinal velocity component in the wake beyond the cone and body of rotation in the form of the following dependences:

$$\sqrt{\overline{u'^2}} | u; \sqrt{\overline{u'^2}} | u_\infty \text{ if } \left( \sqrt{\overline{u'^2}} | u \right) / \left( \sqrt{\overline{u'^2}} | u \right)_m \text{ of } y | \delta_{i/2},$$

where  $\delta_{1/2}$  is determined from the profile defect in the averaged velocity.

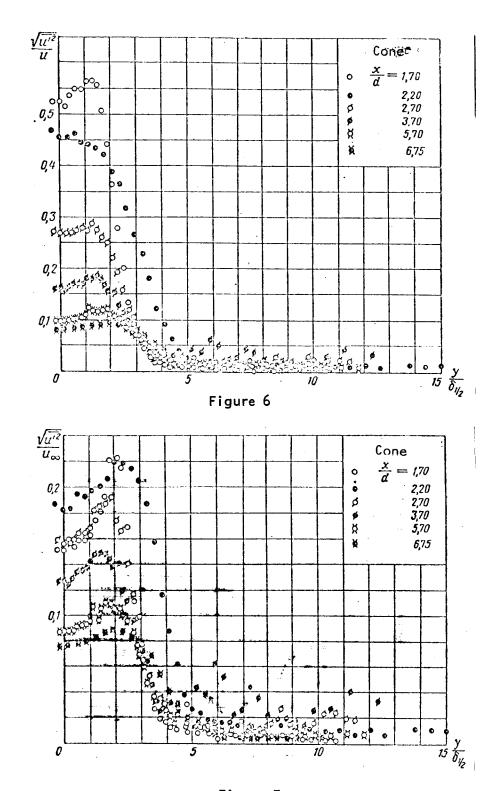


Figure 7

Thus, in the axisymmetrical wake beyond a poorly streamlined body, we can note three characteristic sectors: the first sector, the area of reverse fluid flow. In the first sector, a considerable deviation from isobaric flow is noted, and a high level of turbulence is generated. The second and third

sectors, the transient and primary sectors, encompass the area of primary direction flow in the medium. In the transient sector, the level of turbulence is high, and the gradient of  $\overline{u}^2$  is considerable with respect to x. Here, the regularity of development of the wake along its length, characteristic for greater distances from the body, is disrupted.

The characteristic properties of the main sector are isobaric and universal velocity profiles, insignificant gradient  $\overline{u}^2$  with respect to x; these properties are well known.

As follows from Figure 1, even in the main sector of the wake beyond the cone the velocity profile differs considerably from the ordinary, universal "stream" profile characteristic for the wake beyond a streamlined body of rotation [1, 8]. This conclusion agrees satisfactorily with the results of the experimental investigations of Reichardt [10]. The velocity profile which he measured in the wake beyond a cone and a disk are shown on Figure 12.



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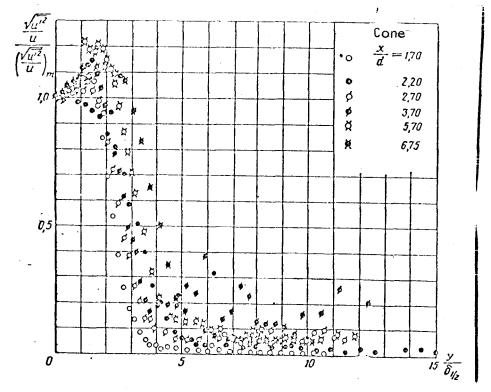
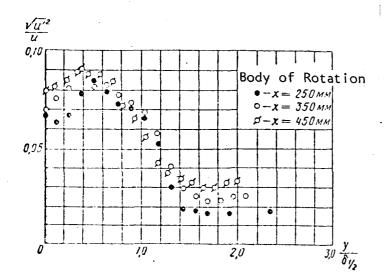


Figure 8

Investigation of the discontinuous flow beyond the step in a closed channel (Figure 13) showed the following. With a relative height of the intake cross section  $\overline{H}$  = H/h, equal to 0.4 and 0.8, over the length of a channel equal to approximately four times the step height, an increase in the potential flow velocity of approximately 5% in comparison to the velocity in the intake cross



section is noted (Figure 14). Where  $\overline{H} = 1.62$  and 2.80, this increase in velocity is practically not observed (Figure 15). It should be noted that the results of measurements using the Pitot-Prandtl tubes, the three-tube fitting and the thermoanemometer correspond over most of the velocity profile. divergence between the indications of these instruments occurs near the line of zero longitudinal velocities. Figure 14 shows the velocity profiles measured by the Pitot-Prandt1 tubes, Figure 15 shows those measured by the thermoanemometer.

Figure 9

The length of the sector of reversed flow beyond the step, as the direct measurements showed, and also as was shown by photography of the silk threads, depends on two parameters: height of the intake cross section and height of the step. With constant height of the input cross section, the length of the reverse flow area  $l \approx (4.5\text{-}6.5)$  h. With constant height of the step, increasing the input height  $\overline{H}$  causes the length of the reverse flow area to decrease. The graph of this dependence is shown on Figure 16. With large values of  $\overline{H}$ , the flow in the reverse flow area corresponds to a flow in the wake beyond a poorly streamlined body in an infinite flow.

The photographs on Figure 17 show the flow picture at  $\overline{H}$  = 2.80 and 0.62. We see here that in a narrow channel even the threads located outside the area of circulation flow are subject to broad oscillations. The pulsations arising in the circulation zone propagate into the external flow area. In a broad channel, the action on the external flow is not so significant. The profiles of turbulence intensity shown on Figure 15 indicate that just as in the case of the wake beyond a cone, turbulization of the external flow occurs, being damped only far beyond the limits of the boundary layer.

A change in input cross section height influences the distribution of pressure on both walls of the channel and at the same time has practically no influence on the pressure at the step. The measurements of static pressure on the walls and on the step which we performed were designed to show the distribution of the pressure coefficient  $c_p = (p - p_{in})/(1/2)\rho u_{in}^2$ , where p is the static pressure at the point in question;  $p_{in}$  and  $u_{in}^2$  are the pressure and velocity in the narrow cross section of the channel 50 mm from the step.

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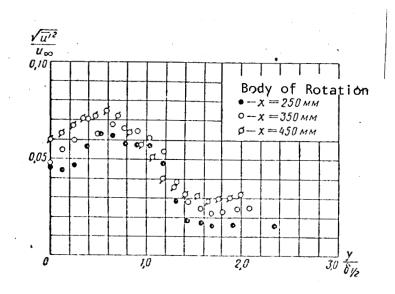


Figure 10

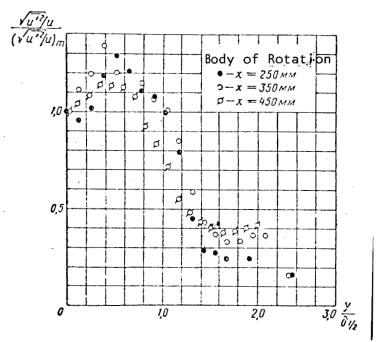
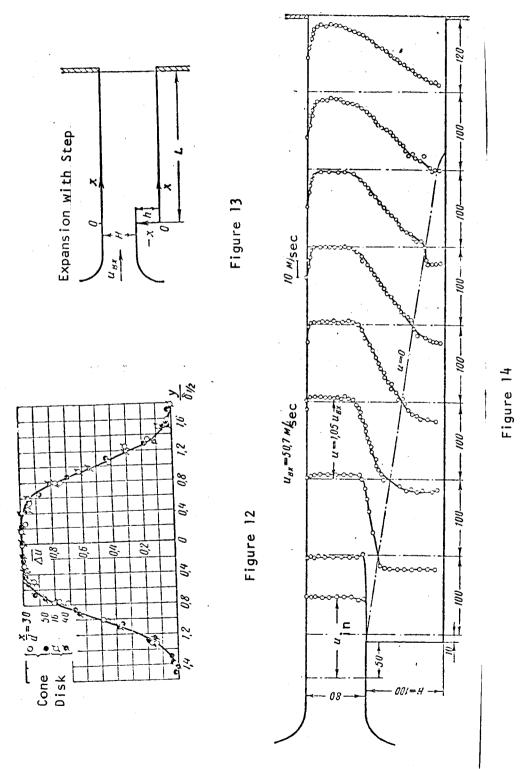


Figure 11



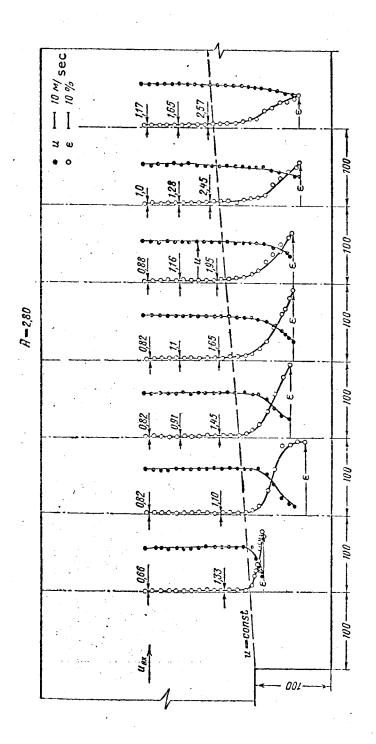
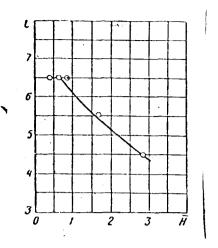


Figure 15



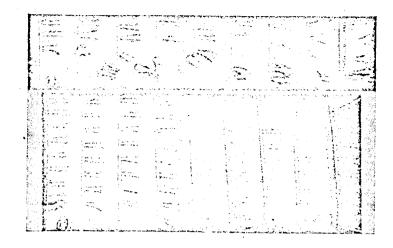
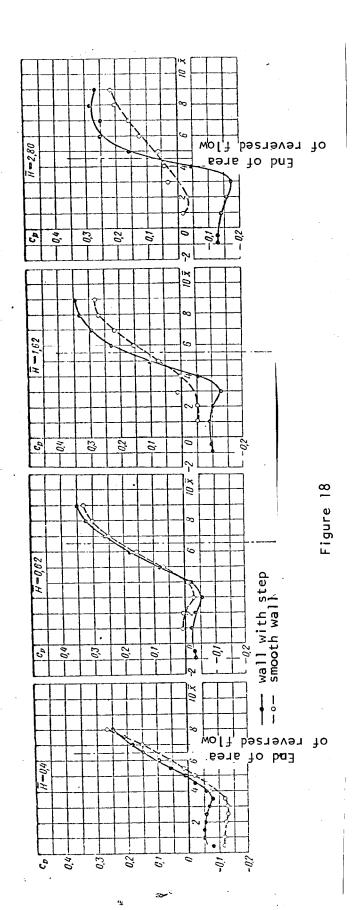


Figure 16

Figure 17

Figure 18 shows the results of measurement of  $c_p$  as a function of relative distance  $\overline{x}$  = x/h from the beginning of the expansion for both walls with a velocity in the input cross section  $u_{in}$  = 32 m/sec. With increasing relative height of the input cross section, the distribution of the pressure coefficient on the walls becomes different. The distribution of the pressure coefficient on the step is given on these same graphs by the curves with x < 0. It follows from this that  $c_p$  on the step depends little on the height of the input cross section  $\overline{H}$ .



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